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Indian Standard

SPECIFICATION FOR MONOCRYSTALLINE SEMICONDUCTOR RECTIFIER CELLS AND STACKS

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INDIAN STANDARDS INSTITUTION
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

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February 1967

Indian Standard

SPECIFICATION FOR MONOCRYSTALLINE SEMICONDUCTOR RECTIFIER CELLS AND STACKS

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Indian Standard
SPECIFICATION FOR MONOCRYSTALLINE SEMICONDUCTOR RECTIFIER CELLS AND STACKS

0. FOREWORD

0.1 This Indian Standard was adopted by the Indian Standards Institution on 19 December 1966, after the draft finalized by the Power Converters Sectional Committee had been approved by the Electrotechnical Division Council.

0.2 Power diodes making use of rectifier cells and stacks of monocrystalline semiconductor type, for example, germanium and silicon, have proved to be very suitable for conversion of ac into dc for voltages up to 5 000 V. The manufacture of such rectifier has already started in this country. This specification is intended to give the necessary guidance to the manufacturers and users.

0.3 This specification covers cells and stacks of monocrystalline semiconductor type. The completed rectifier assemblies and equipments making use of these cells and stacks would be covered by a separate specification.

0.4 This standard contains clauses which call for agreement between the purchaser and the supplier or which permit the purchaser to use his option for selection to suit his requirements or which require the purchaser to supply certain technical information at the time of placing orders. The relevant clauses are **3.1.2**, **3.2.2**, **3.3.1**, **3.5.2**, **3.6**, **5.5** and **6.1.6**.

0.5 In the preparation of this standard, assistance has been derived from IEC Publication No. 146-1963 'Monocrystalline semiconductor rectifier cells, stacks, assemblies and equipments' issued by International Electrotechnical Commission.

0.6 For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test, shall be rounded off in accordance with IS : 2-1960*. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

1. SCOPE

1.1 This standard applies to monocrystalline semiconductor rectifier cells and stacks having a rated output per cell of 10 W and above, used in power diodes for supplying dc power from ac sources at frequencies up to 2 000 c/s and voltages not exceeding 5 000 V.

*Rules for rounding off numerical values (*revised*).

1.2 In so far as it is applicable, this standard relates also to controlled semiconductor devices having trigger characteristics. More detailed treatment of controlled semiconductor devices (that is, thyristors) would be dealt with in a separate standard.

1.3 This standard does not apply to telecommunication rectifiers other than those for power supplied to such apparatus, nor to rectifiers used as auxiliaries to measuring instruments. Further, it does not include the mains transformer or other associated transformers and apparatus, nor does it apply to rectifiers based on polycrystalline semiconductor materials.

2. TERMINOLOGY

2.0 For the purpose of this standard, the following definitions shall apply.

2.1 General Terms

2.1.1 *Rectifier* — A device for converting an alternating or oscillating current into a unidirectional current, either by inversion or suppression of alternate half-waves.

2.1.2 *Semiconductor Rectifier* — A rectifier using the properties of a semiconductor as the basis of operation.

2.1.3 *Rectifier Junction* — A junction in a monocrystalline semiconductor material which presents an asymmetrical conductivity according to the polarity of the voltage applied to it (*see* Fig. 1).

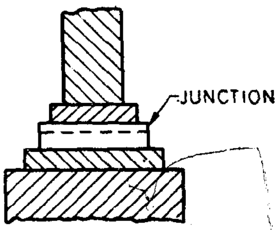


FIG. 1 RECTIFIER JUNCTION

2.1.4 *Rectifier Cell* (*Rectifier Diode*) — The elementary rectifying device, consisting of one or more rectifier junctions which presents an asymmetrical conductivity complete in its envelope with means of cooling, if integral with it (*see* Fig. 2).

2.1.5 *Controlled Rectifier Cell* (*Thyristor*) — A rectifier cell with one or more rectifier junctions, the conductivity of which may be controlled by electrical signals supplied to one or more control terminals (*see* Fig. 3).

NOTE — Rectifier cells, controlled by non-electrical means, for instance, light or magnetic field, are not included.

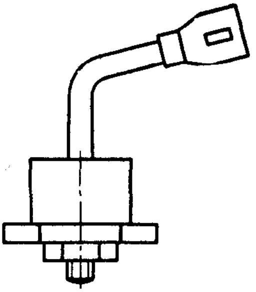
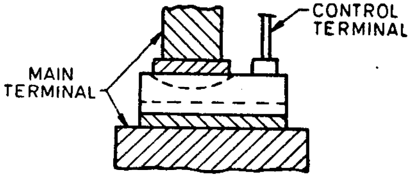


FIG. 2 RECTIFIER CELL



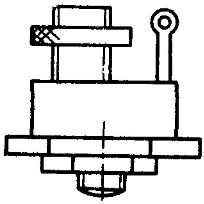


FIG. 3 CONTROLLED RECTIFIER CELL

2.1.6 *Rectifier Stack* — A single structure of one or more rectifier cells with its (their) associated mounting(s), cooling attachments, if any, and connections whether electrical or mechanical (*see* Fig. 4).

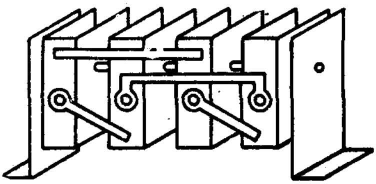


FIG. 4 RECTIFIER STACK

2.1.7 *Rectifier Assembly* — An electrically and mechanically combined assembly of cells or stacks, complete with all its connections, together with means for cooling, if any, in its own mechanical structure (*see* Fig. 5).

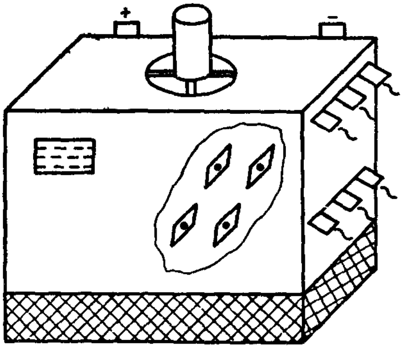


FIG. 5 RECTIFIER ASSEMBLY

2.1.8 *Rectifier Equipment* — An operative assembly comprising one or more rectifier assemblies, together with transformers, essential switching devices and other auxiliaries, if any, for the conversion of alternating current to direct current (*see* Fig. 6).

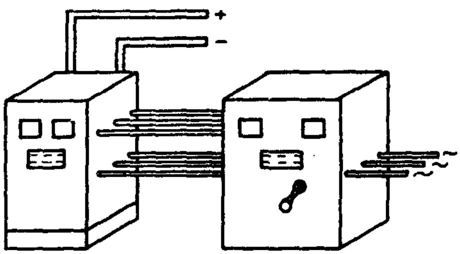


FIG. 6 RECTIFIER EQUIPMENT

2.1.9 *Rectifying Element* (*Rectifier Circuit Element*) — A circuit element bounded by one positive and one negative terminal, and having the characteristic of conducting current effectively in only one direction (*see* Fig. 7).

NOTE — In practice, a rectifying element may be derived from one cell, or a number of cells interconnected in either a series, a parallel, or a series-parallel arrangement. That means that the corresponding component may be either the part or the whole of a stack or a stack assembly.

2.1.10 *Rectifier Connection* — A method of connecting one or more rectifying elements for the conversion of alternating current to direct current (*see* Fig. 8).

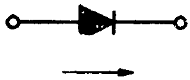


FIG. 7 RECTIFYING ELEMENT

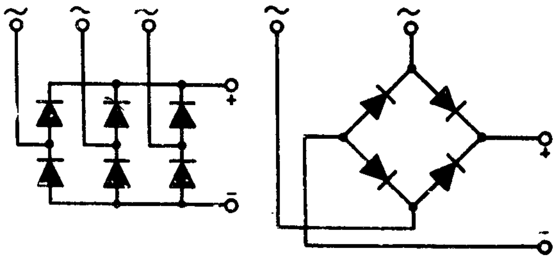


FIG. 8 RECTIFIER CONNECTION

2.1.11 *Arm of a Rectifier Connection* — One rectifying element of a rectifier connection (*see* Fig. 9).

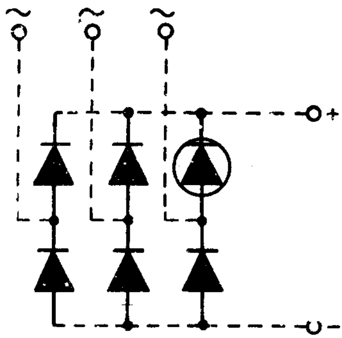


FIG. 9 ARM OF A RECTIFIER CONNECTION

2.1.12 *Single-Way Connection* — A method of connection such that each of the phase terminals of the ac circuit or of the transformer cell windings is connected only to one terminal of one arm of a rectifier connection (*see* Fig. 10).

2.1.13 *Double-Way Connection* — A method of connection such that each of the phase-terminals of the ac circuit or of the transformer cell windings, is connected to an interconnection of two arms of a rectifier connection, the two arms being interconnected with terminals of opposite polarity (*see* Fig. 11).

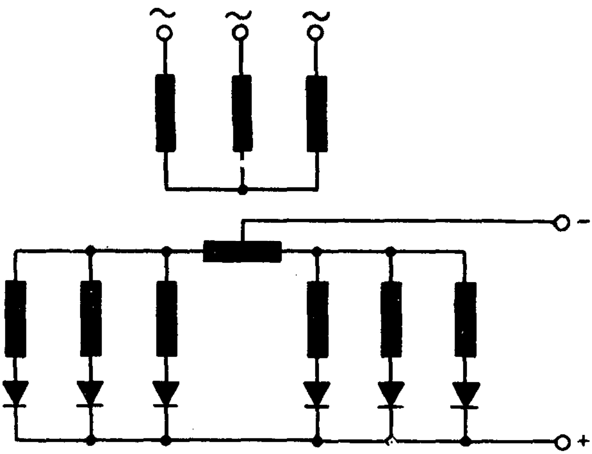


FIG. 10 SINGLE-WAY CONNECTION

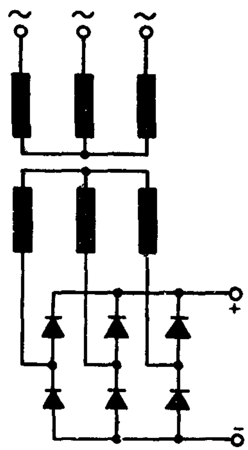


FIG. 11 DOUBLE-WAY CONNECTION

2.1.14 *Pulse Number, p* — A characteristic of a rectifier connection expressed as the number of non-simultaneous commutations occurring during one cycle of applied alternating voltage (*see* Fig. 12).

2.1.15 *Commutating Group* — A group of cells and phases which commutate independently of the others. Such a group shall include all windings whose commutations are simultaneous.

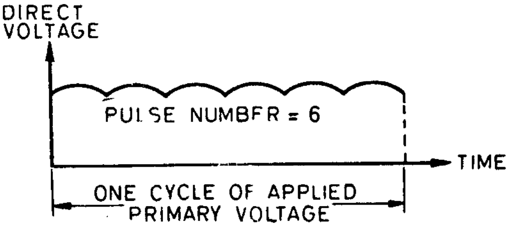


FIG. 12 PULSE NUMBER

2.1.16 *Commutating Number, q* — The number of commutations occurring during one cycle in each commutating group.

2.1.17 *Type Tests* — Tests carried out to prove conformity with the requirements of this specification. These are intended to prove the general qualities and design of a given type of rectifier cell and stack.

2.1.18 *Routine Tests* — Tests carried out on each rectifier cell and stack to check requirements likely to vary during production.

2.2 Electrical Characteristics of Rectifier Cells

2.2.1 *Forward Direction* — The direction in which a rectifier cell has the higher conductance.

2.2.2 *Forward Voltage Drop* — The voltage drop which results from the flow of current in the forward direction.

2.2.3 *Threshold Voltage, U_{th}* — The value of the forward voltage drop obtained at the intersection with the axis for zero current of a straight line, approximating the forward voltage-current characteristic of the cell (*see* Fig. 13).

NOTE — A recommended approximation is a straight line, crossing the voltage current characteristic of the cell at 0·5 and 1·5 times peak value of rated current as specified in **3.2**.

2.2.4 *Differential Resistance, r_f* — The value of forward resistance, calculated from the slope of the straight line, used when determining the threshold voltage.

NOTE — Both threshold voltage and differential resistance are temperature dependent.

2.2.5 *Reverse Direction* — The direction in which a rectifier cell has the lower conductance.

2.2.6 *Reverse Current* — The current which flows in the reverse direction of a rectifier cell.

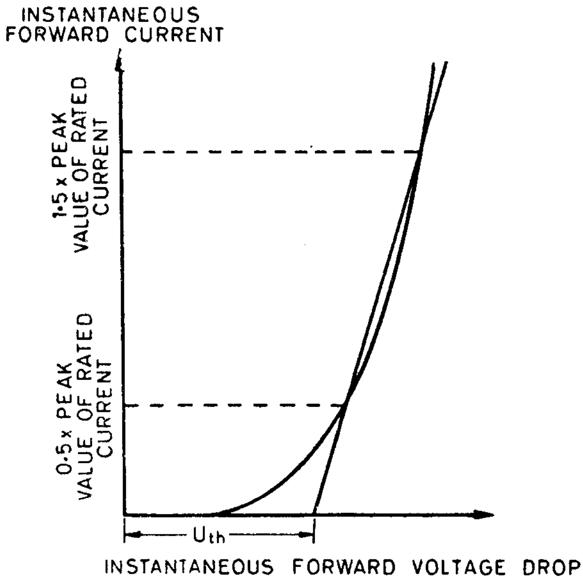


FIG. 13 THRESHOLD VOLTAGE

2.2.7 *Forward Current* — The current which flows in the forward direction of a rectifier cell.

2.3 Electrical Characteristics of Rectifying Elements

2.3.1 *Instantaneous Forward Voltage Drop* — The instantaneous value of forward voltage drop (**2.2.2**) of a rectifying element at a given forward current.

2.3.2 *Average Forward Voltage Drop, U_a (Averaged Over a Full Cycle)* — The value of the forward voltage drop (**2.2.2**) of a rectifying element averaged over a full cycle of specified wave-shape.

2.3.3 *Average Forward Conduction Voltage Drop* — The value of the forward voltage drop (**2.2.2**) of a rectifying element averaged over a forward conduction period of a specified wave-shape.

2.3.4 *Instantaneous Reverse Current* — The instantaneous value of reverse current (**2.2.6**) at a given reverse voltage.

2.3.5 *Average Reverse Current* — The value of reverse current (**2.2.6**) through a rectifying element and averaged over a full cycle with specified magnitude and wave-form of applied voltage.

2.3.6 *Average Forward Current, I_a* — The value of the current in the forward direction of a rectifying element, excluding the reverse current and averaged over a full cycle (*see* Fig. 14).

NOTE — Forward current ratings for cells and stacks are assigned by the manufacturer in accordance with **3.2**.

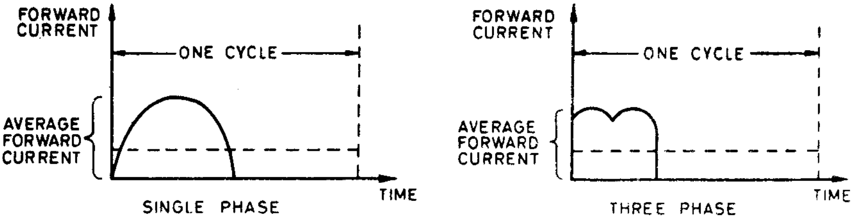


FIG. 14 AVERAGE FORWARD CURRENT

2.3.7 *Peak Working Reverse Voltage, U_r* — The peak value of the circuit voltage applied across the cell or rectifying element in the reverse direction, excluding recurrent oscillatory overvoltages due to commutation (**2.3.8**) and excluding random transient overvoltages (**2.3.9**) (*see* Fig. 15).

2.3.8 *Maximum Recurrent Reverse Voltage, U_{rm}* — The maximum value of the periodic overvoltage impressed across the cell or rectifying element in the reverse direction including circuit effects such as commutation, but excluding random transient overvoltages (**2.3.9**) (*see* Fig. 15).

2.3.9 *Peak Transient Reverse Voltage, U_{rt}* — The peak value of any non-periodic surge voltage impressed across the cell or rectifying element in the reverse direction, due to a random circuit transient (*see* Fig. 15).

NOTE 1 — The voltage defined by **2.3.7** is the peak value of the nominal circuit voltage for the rectifier connections (including ac supply voltage variations).

NOTE 2 — The voltage defined by **2.3.8** occurs in a rectifier connection due to rectifier junction properties in conjunction with circuit constants, and is to some extent under the control of the connection designer.

NOTE 3 — The causes of surge voltages defined by **2.3.9** are usually outside the control of the connection designer, but these voltages may often be minimized by the provision of surge suppression components.

NOTE 4 — Reverse voltage ratings for cells and stacks are assigned by the manufacturer in accordance with **3.4**. Cells and stacks whose reverse dissipation is significant may be assigned different rated values of the periodic voltages defined by **2.3.7** and **2.3.8**. In many cases a further rating will be assigned for the non-periodic surge voltage defined in **2.3.9**.

2.4 Cooling

2.4.1 *Natural Air Cooling* — Cooling by the natural convection of the ambient air.

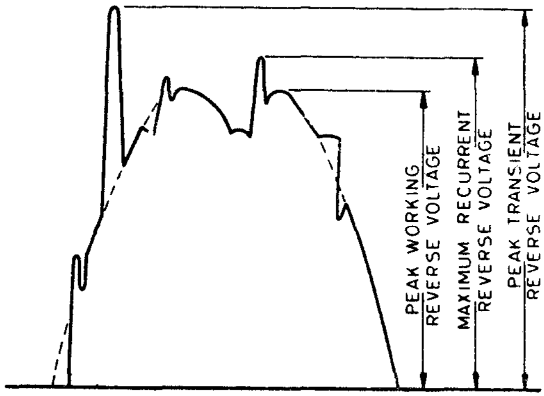


FIG. 15 ILLUSTRATION FOR REVERSE VOLTAGES

2.4.2 *Cooling by Forced Ventilation* — Cooling by a forced ventilation arrangement, for example, a fan. The cooling air may be taken from the immediate proximity or from a place at a different temperature from that of the ambient air.

2.4.3 *Tap Water Cooling* — Cooling by water from an external supply.

2.4.4 *Fluid-to-Air Cooling* — Cooling by a circulating heat transfer agent (gas or liquid) which is cooled by air. The fluid circulation and the air cooling may be natural or forced.

2.4.5 *Fluid-to-Water Cooling* — Cooling by a circulating heat transfer agent (gas or liquid) which is cooled by water from an external supply, either in a heat exchanger or in a cooling duct within the fluid. The fluid circulation may be natural or forced.

2.4.6 *Liquid Immersed Natural Cooling* — Cooling by a thermo-siphon circulating liquid heat transfer agent which is cooled by natural air circulation on the outside of the container.

2.4.7 *Liquid Immersed Forced Cooling* — Cooling by a thermo-siphon circulated liquid which is cooled by forced air cooling on the outside of the container.

2.4.8 *Ambient Temperature for Semiconductor Stacks Rated for Natural Air Cooling* — The temperature of the air directly below the rectifier stack when it is in service under rated service conditions.

2.4.9 *Cooling Air Temperature for Semiconductor Stacks Rated for Cooling by Forced Ventilation* — The temperature of the cooling air immediately before its entry into the stacks.

2.4.10 *Cooling Medium Temperature* — The temperature of the incoming cooling medium.

3. RATINGS

3.1 Cooling Conditions and Cell Temperature

3.1.1 *Cells or Stacks with Cooling Body* — For rectifier cells or stacks supplied with their own heat dissipating arrangements, such as lead-mounted cells, cells with integral fins or finned stacks, the cooling conditions shall be specified as follows:

a) The ambient temperature and altitude in the case of natural air cooling;

b) The cooling air temperature, velocity and altitude in the case of forced air cooling; and

c) The cooling medium and its temperature in the case of liquid cooling.

3.1.2 *Cells or Stacks Without Cooling Body* — For rectifier cells, such as stud or base mounted cells, supplied for use with the purchaser's heat dissipating arrangements (for example, a fin, or a fluid cooled chamber to which the cell is attached), the cell temperature at a prescribed measuring point of the cell shall be specified. The method for the cell temperature measurement shall also be specified.

NOTE — For this type of cells or stacks, the user shall ensure that the specified working temperature is not exceeded.

3.2 Average Forward Current

3.2.1 *Rectifying Element* — For a rectifier cell or rectifier stack forming a rectifying element (**2.1.9**), the rated average forward current shall be given in terms of a single phase connection with resistive load. Conversion factors applicable to other connections and loads may be given.

3.2.2 *Rectifier Connection* — For a rectifier stack forming a rectifier connection (**2.1.11**), the rated average forward current shall be given in terms of stack output current to a resistive load unless otherwise specified.

NOTE 1 — When rectifier cells or rectifier stacks are connected in parallel, precautions shall be taken to ensure that they operate within their average forward current rating.

NOTE 2 — Ratings specified under **3.1**, **3.2**, **3.3** and **3.4** are inter-related.

NOTE 3 — For different temperatures at the reference point (*see* **3.1.2**), different rated currents may be given.

3.3 Forward Overload Current

3.3.1 The permissible overloads may be specified by an equipment rating class or by any one of methods described in **3.3.2** and **3.3.3**.

Whichever method is adopted for specifying the overloads, the following information shall be given:

a) Rated cooling conditions and cell temperature (**3.1.1** or **3.1.2**),
b) Immediate previous loading condition, and
c) Whether or not the overloads are to be followed by the restoration of reverse voltage after each current pulse.

3.3.2 Overloads higher than those given by an equipment rating class are preferably characterized by the two curves given in Fig. 16 and 17 for times longer than the time of one cycle. For single overload from a specified base load, Fig. 16 is used.

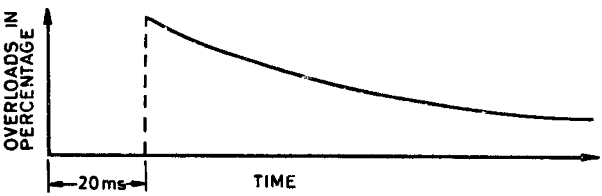


FIG. 16 OVERLOADS FROM SPECIFIED BASE LOAD

If the frequency of overloads is such that the overload capacity is reduced, Fig. 17 is used in conjunction with Fig. 16.

NOTE — Figures 16 and 17 assume that the wave-shape of current is the same during overload as during base load. In practical cases, however, this is seldom true, and the change of wave-shape should be considered when applying these ratings in critical cases.

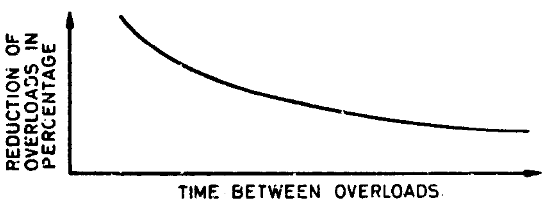


FIG. 17 REDUCED OVERLOAD

3.3.3 Overloads which are only sustained for part of a cycle may often be characterized by the expression:

$$\int_0^{t_2} P \, dt$$

where

P = instantaneous value of power loss developed in the cell, and

t_2 = permissible overload time.

For very short times (≤ 3 ms), the permissible load may approximately be expressed by:

$$\int_{0}^{t_2} I^2 \, dt$$

where

I = instantaneous value of current through the cell.

NOTE 1 — Where rectifier cells or rectifier stacks are connected in parallel, precautions shall be taken to ensure that they operate within their forward overload current rating.

NOTE 2 — Ratings specified under **3.1**, **3.2**, **3.3** and **3.4** are inter-related

3.4 Reverse Voltage

3.4.1 *Rated Peak Working Reverse Voltage,* U_{rl} — It is the higher permissible peak working reverse voltage (**2.3.7**) of a rectifier cell or rectifying element of a rectifier stack, assigned to it by the manufacturer under specified service conditions including temperature, forward current and circuit connection.

3.4.2 *Rated Maximum Recurrent Reverse Voltage,* U_{rml} — It is the highest permissible recurrent reverse voltage (**2.3.8**) of a rectifier cell or rectifier stack forming a rectifying element, assigned to it by the manufacturer under specified service conditions including temperature, forward current and circuit connection.

3.4.3 *Rated Peak Transient Reverse Voltage,* U_{rtl} — It is the rated value, assigned by the manufacturer, of the peak transient reverse voltage (**2.3.9**) that may be impressed across a rectifier cell or rectifying element of a rectifier stack under specified service conditions including temperature, forward current and circuit connection.

For this purpose reference may be made to the voltage that the rectifier will withstand in a specified test circuit.

NOTE 1 — Where rectifier cells or rectifier stacks are connected in series, precautions shall be taken to ensure that every cell operates within its reverse voltage rating for this condition.

NOTE 2 — Ratings specified in **3.1, 3.2, 3.3** and **3.4** are inter-related.

NOTE 3 — For stacks and cells, no increase of the peak working reverse voltage or maximum recurrent reverse voltage or peak transient reverse voltage above the rated values is permitted. Allowance for this shall be made when selecting the voltage ratings of cells and stacks used in assemblies and equipment.

3.5 Ambient Temperature

3.5.1 The basic rating shall apply to 40°C ambient temperature.

3.5.2 Other ambient temperatures of 45°C, 55°C and 70°C are also recognized and the manufacturer shall, on the request of the purchaser, provide a rating for the required temperature(s).

3.6 Types of Load — For the purposes of rating, the type of rectifier load should be specified, that is, resistive load, inductive load, capacitive load, battery load, machine load or combination of loads. If not otherwise specified, the load shall be taken to be resistive.

4. MARKING

4.1 Each rectifier cell and stack shall be clearly and indelibly marked with the following information:

a) The manufacturer's name and/or trade-mark;
b) Date of manufacture (may be given by quarter);
c) Country of manufacture; and
d) For stacks, the following symbols or colours for the terminal markings:

Terminal	*Symbol*	*Colour*
ac	∼	Yellow
dc positive	+	Red
dc negative	—	Blue

4.2 A reference code giving all ratings and other information according to this specification shall be given.

4.3 The forward direction of each cell shall be indicated by an arrow.

4.4 Rectifier cells and stacks may also be marked with the ISI Certification Mark.

NOTE — The use of the ISI Certification Mark is governed by the provisions of the Indian Standards Institution (Certification Marks) Act and the Rules and Regulations made thereunder. The ISI Mark on products covered by an Indian Standard conveys the assurance that they have been produced to comply with the requirements of that standard under a well-defined system of inspection, testing and quality control which is devised and supervised by ISI and operated by the producer. ISI marked products are also continuously checked by ISI for conformity to that standard as a further safeguard. Details of conditions under which a licence for the use of the ISI Certification Mark may be granted to manufacturers or processors, may be obtained from the Indian Standards Institution.

5. TESTS

5.1 General

5.1.1 *Type Tests* — The following shall constitute the type tests:

a) Forward and reverse characteristics curves (**5.2**)

b) Forward voltage drop test (**5.3**)

c) Reverse voltage test (**5.4**)

d) Insulation test (**5.5**)

e) Load test (**5.6**)

f) Power losses (**5.7**)

g) Temperature-rise test (**5.8**)

5.1.2 *Routine Tests* — The following shall be carried out as routine tests

a) Forward voltage drop test (**5.3**)

b) Reverse voltage test (**5.4**)

c) Insulation test (**5.5**)

5.2 Forward and Reverse Characteristics Curves — This shall be carried out as a measurement of instantaneous values as given in **5.2.1**.

5.2.1 *Measurement of Instantaneous Values* — In normal service the temperature of the junction fluctuates during the intervals of forward current and reverse voltage. This temperature fluctuation is, however, dependent upon the length of the intervals, that is, it is dependent upon the connection.

Measurements of the instantaneous values, therefore, should be made with the actual connection with the correct alternation of forward current and reverse voltage. Such measurements, however, are difficult and the validity is restricted to this connection. This is true especially for the reverse current while the forward voltage drop is less dependent on the cyclic temperature variation.

In view of these difficulties and the restricted value of such measurements, it is recommended that forward voltage drop and reverse current be measured separately under well defined conditions.

5.2.1.1 *Forward voltage drop, instantaneous value* — The forward voltage drop shall be measured in a connection giving a current as stated under **3.2.1** and with the reference point of the cell at rated temperature. The test has to be performed at a sufficiently low voltage to obviate the influence of reverse voltage on the oscilloscope.

During these measurements the temperature variations will be the same as in actual service with single-phase connection and resistive load, as the reverse losses are negligible.

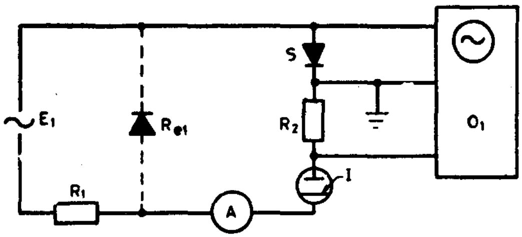
In taking these measurements due consideration should be given to stray magnetic fields which may cause measurement errors.

An example of a measuring circuit is given in Fig. 18.

5.2.1.2 *Reverse current, instantaneous value* — Reverse current shall be measured in a connection giving a reverse voltage corresponding to single-phase connection and resistive load, but the forward current shall be small compared with rated current. The measurements shall be carried out at

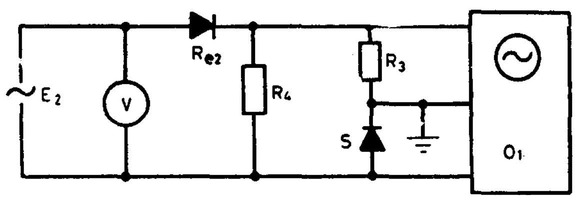
stated values of voltage and temperature. During these measurements, the temperature of the junction will be practically the same as that of the reference point.

An example of a measuring circuit is given in Fig. 19.



S	Test specimen
I	Unidirectional device having negligible leakage current (for instance, ignitron)
R_1, R_2	Resistors
R_{e1}	Rectifying element (to avoid dc loading of current source)
O_1	Oscilloscope
E_1	Sinusoidal ac voltage source
A	Ammeter

FIG. 18 MEASUREMENT OF INSTANTANEOUS FORWARD VOLTAGE DROP



V	Voltmeter
S	Test specimen
R_3, R_4	Resistors
R_{e2}	Rectifving element (to avoid forward current in S)
E_2	Sinusoidal ac voltage source
O_1	Oscilloscope

FIG. 19 MEASUREMENT OF INSTANTANEOUS REVERSE CURRENT

5.2.1.3 *Presentation of data* — When the forward and reverse characteristics of a cell are presented in graphical form, the arrangement in Fig. 20 is recommended. The shaded area represents the range of variation between different cells. It shall be clearly specified that the curves show instantaneous values.

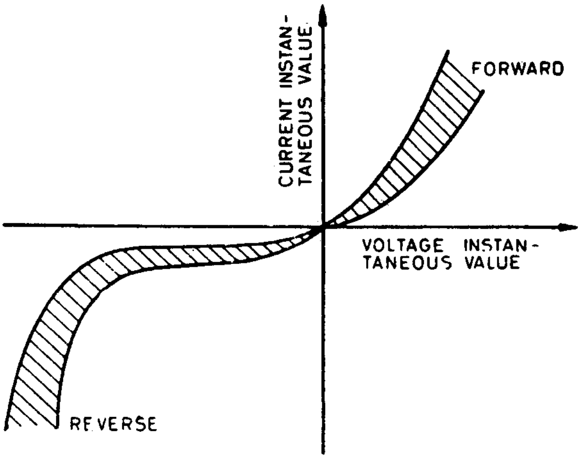


FIG. 20 PRESENTATION OF DATA

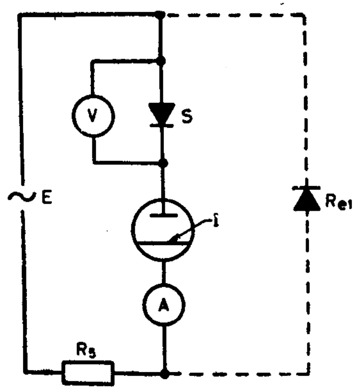
5.3 Forward Voltage Drop Test — The average forward voltage drop (**2.3.2**) may be measured with circuit shown in Fig. 21. The specimen will then operate without reverse voltage and with a current wave-shape corresponding to single-phase operation with resistive load.

5.3.1 The voltage developed across the cell shall be measured. It shall not deviate from the rated value by more than the specified tolerance.

5.4 Reverse Voltage Test — Each cell or stack shall withstand for 3 seconds, without injury, a half-wave sinusoidal voltage having a peak value, measured across the cell, equal to the rated maximum recurrent reverse voltage.

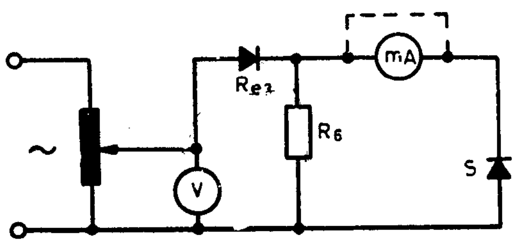
The test shall be performed with the reference point at a temperature so much higher than rated temperature as corresponds to the temperature drop from the junction to the reference point in rated service.

The test may be carried out with the circuit shown in Fig. 22. The milliammeter is not essential but indicates average reverse current, which is conveniently measured by this method for reference purposes.



S	Test specimen
V	Moving-coil voltmeter showing average forward voltage drop
A	Moving-coil ammeter showing average forward current
R_5	Load resistor
R_{e1}	Rectifying element (to avoid dc loading of current source)
I	Unidirectional device having negligible leakage current (for instance ignitron)
E	Sinusoidal ac voltage source

FIG. 21 MEASUREMENT OF AVERAGE FORWARD VOLTAGE DROP



S	Test specimen
V	RMS voltmeter
mA	Moving-coil milliammeter
R_6	By-pass resistor
R_{e3}	Rectifying element to prevent forward current in the specimen

FIG. 22 CIRCUIT FOR REVERSE VOLTAGE TEST

5.5 Insulation Test — When the stack is provided with a mounting device and is insulated from it, the insulation shall be tested in the following manner:

Before applying the test voltage, all of the terminals of all cells or series groups of cells shall be joined together to ensure that the high voltage shall not be applied across the cells.

The insulation between the short-circuited terminals and the metallic parts of the mounting device, shall withstand an ac test voltage for one minute.

Unless otherwise agreed, the rms value of the test voltage shall be:

$$2\ 000 \text{ V or } \frac{2\ U_{rp}}{\sqrt{2}} + 1\ 000 \text{ V}$$

whichever is greater, where U_{rp} is the highest rated crest working voltage between any pair of terminals.

The test voltage shall be applied gradually, starting at 50 percent and increasing to full value in not less than 10 seconds.

The test shall be performed at room temperature.

For stacks to be used in electrically exposed conditions*, or where considerable switching over-voltages are to be expected, the test voltage may be increased by agreement between the purchaser and the supplier.

5.6 Load Test — The purpose of this test is to verify that the cells or stacks are capable of meeting the requirements of **3.2** and **3.3**.

The specified method of cooling shall be used and the test shall be carried out at the maximum specified ambient temperature or with the maximum specified cooling medium temperature, as the case may be, and with specified circuit connections.

When the cells may be used for a number of different cooling methods, the test shall be carried out at rated cell temperature (**3.1.2**), unless otherwise specified.

When a stack is to be used at an altitude above 1 000 m, the test shall be carried out at a current which is increased above the specified value by 1·0 percent per 100 m above 1 000 m for natural air cooled stacks and by 1·5 percent for forced air cooled stacks.

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*Installations may be generally classified as electrically exposed when the apparatus is or may be subject to overvoltages of atmospheric origin. Such installations are usually those connected to overhead transmission lines either directly or through a short length of cable, which may amplify certain voltages.

5.6.1 For cells and stacks where ratings are specified according to **3.2** and where the overloads are given in one of the ways mentioned in **3.3**, the rating tests shall be performed to prove that the cells or stacks will carry their rated loads and overloads.

5.6.2 For cells and stacks for use in equipment or assemblies where overloads are specified to suit particular application, the test shall be carried out at not less than the rated peak working voltage and at a duty cycle not less onerous than that specified.

5.7 Power Losses — The power losses shall be calculated from the forward instantaneous characteristics at rated temperature (**5.2.1**) and for the appropriate wave-shape of the forward current. Reverse current shall be ignored.

5.8 Temperature-Rise Test — The stack shall be tested under rated cooling conditions (**3.1**) at a test current such that the same loss will be developed during the test as in normal service. This may be achieved by short-circuiting the dc terminals of the stack and connecting a low-voltage ac supply to the stack input terminals, or by passing direct current through the cells.

When the stack is to be used at an altitude above 1 000 m, the loss during the test shall be increased by the same percentage as that specified for the current in **5.6**.

The temperature-rise at the prescribed measuring point (**3.1.2**) shall have such a value that the rated cell temperature will not be exceeded when operating under rated cooling condition.

6. INFORMATION TO BE GIVEN BY THE MANUFACTURER

6.1 The following information shall be supplied by the manufacturer.

6.1.1 The ratings according to **3**.

6.1.2 Forward current limit to be used for the test in **5.3**.

6.1.3 Instantaneous forward voltage drop plotted against instantaneous current at rated service (**5.2.1.1**).

6.1.4 Instantaneous reverse current plotted against instantaneous reverse voltage at rated service (**5.2.1.2**).

6.1.5 Permissible limits of storage temperature.

6.1.6 In addition, subject to the agreement between the purchaser and the manufacturer, information should be furnished on specific *short time ratings* (**3.3**).

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